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# STRÖMGREN PHOTOMETRY OF THE T TAURI STAR SU AURIGAE: MULTI-TIMESCALE LIGHT VARIATIONS

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Intensive long-term photoelectric photometry of classical T Tauri stars (CTTS) can provide fundamental new information that helps to understand stars in the early stages of evolution. CTTS typically have spectral types from F to K, exhibit weak H$\alpha$ and Ca II H & K emissions, have broad absorption lines (implying rapid rotation), and are located well above the main-sequence. One of the brightest archetypical CTT stars, SU Aurigae (HD 282624; G2 IIIe; $\langle V \rangle = +9\overset{m}{.}20$; $\langle B-V \rangle = +0\overset{m}{.}90$) is observed to undergo rapid and dramatic light variations. These light variations appear not to be accompanied by spectral changes (Herbst & Shevchenko, 1999). This implies possible obscuration of the star by dust with properties similar to the interstellar medium (ISM). In a previous paper by the authors (DeWarf *et al.*, 1998; hereafter Paper I), the interstellar absorption of SU Aur was determined, and when combined with the Hipparcos distance, yielded estimates of its absolute magnitude and intrinsic colors. These values placed SU Aur about 1.8 mag above the main-sequence for its respective unreddened spectral type. In Paper I, SU Aur was plotted on pre-main sequence (PMS) evolution tracks and an age of about 4 Myrs and a mass of $1.9 \pm 0.1\ M_{\odot}$ was ascertained. The observations presented here were made using the 0.8-m Four College Automatic Photoelectric Telescope (APT), in Arizona. This concentrated (nightly) photometry, has began in October 1993 and continuing to the present, is made in the Strömgren *uvby* system. A description of the instrumentation, observing, and reduction procedure is given in Paper I.

After analyzing the data collected since 1993, large ($\Delta V \approx \Delta y \approx 0\overset{m}{.}40$) "eclipse-like" dimming events have been observed frequently. Representative photometry from the 1998/99 observing season is shown in Fig. 1. In the figure the Strömgren $b$ magnitudes and the corresponding Strömgren $[c_1]$ and $[m_1]$ indices (Strömgren, 1966; Crawford & Mandwewala, 1976) are plotted against Heliocentric Julian Day. As shown, the light variations of SU Aur, like many T Tauri stars, are complicated. In addition to the short-term "dips" in the light curve, the star also varies on time scales of days, months, and years. Excluding the dips, the overall light variations in $b$ are between $b_{\max} \simeq +9\overset{m}{.}75$ to $b_{\min} \simeq +10\overset{m}{.}20$ over September 1998 to March 1999. As shown in the upper panel of Fig. 1, four large dimming events were observed nearly 48 days apart, lasting several days each. To understand the possible cause of such drops, the reddening-independent $[c_1]$ and $[m_1]$ indices were calculated. For data from 1993 to the present we find average values of $0\overset{m}{.}30 \pm 0\overset{m}{.}060$ and $0\overset{m}{.}50 \pm 0\overset{m}{.}087$ for $[c_1]$ and $[m_1]$ respectively. As seen in Fig. 1, these indices do not show any significant variation, though the $b$ filter light varies by more than

$0.^{m}75$. It is therefore reasonable to conclude that orbiting concentrations of dust could produce the observed dimming events, and that this dust has properties similar to that of the ISM. CTT stars are pre-main sequence objects that have extensive accretion disks and SU Aur has a large infrared excess implying a large circumstellar cloud. Hence, it is possible that these dimming events were caused by concentrations of matter orbiting in the outer regions of the disk, by clumps of material surrounding a forming planet, or from dust clouds condensing from ejected matter and, in the process, obscuring the star.

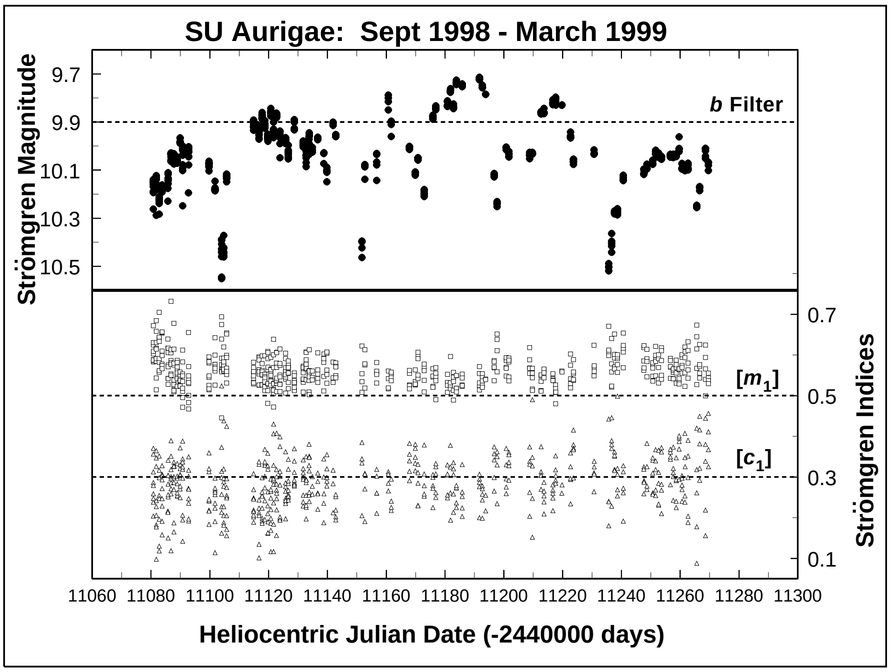


**Figure 1.** The 1998/99 $b$ filter light curve for SU Aur is shown in the top panel with the Strömgren $[c_1]$ and $[m_1]$ indices in the lower panel. The reference lines in the lower panel represent the average values since 1993. Although there are dramatic drops in mean light, the indices remain relatively unaffected. This implies obscuration by dust with properties similar to ISM dust. We find average maximum light levels during this epoch to be about 12.0, 10.8, 9.9, 9.4 mag for $u$, $v$, $b$, and $y$.

The accretion disk and the possible concentrations of matter orbiting around SU Aur are likely being observed nearly edge-on. From speckle interferometry taken along a N-S position angle (DeWarf & Dyck, 1993), the star appears to have no measurable projected spatial extent beyond about 29 AU in the $L'$ band (3.8 $\mu$m). Using the IRAS fluxes (IRAS Point Source Catalog; *Joint IRAS Science Working Group*, 1988), the spectral slope as defined by Adams *et al.* (1987)

$$\eta = \frac{d\log\nu F_\nu}{d\log\nu} \quad\Longrightarrow\quad \eta_{12} \approx \frac{\log\dfrac{\nu_{12}F_{12}}{\nu_{25}F_{25}}}{\log\dfrac{\nu_{12}}{\nu_{25}}}$$

is $-0.65$ for the spectral region between 12 and 25 $\mu$m. Examples of stars that have similarly red spectral slopes are AFGL490, Elias 29, and HL Tau. These stars have resolved infrared emitting circumstellar material projected out to about 1100, 600, and 200 AU respectively (*cf* DeWarf & Dyck, 1993). Of course, as Adams *et al.* (1988) has shown, for circumstellar disk geometry, a high inclination angle will result in significant reddening. HL Tau is an excellent potential candidate for this type of geometry (Lay *et al.*, 1997; Mundy *et al.*, 1996; Sargent & Beckwith, 1991). Therefore, it is likely that for HL Tau and SU Aur, the actual (not just projected) extent of the circumstellar material is less than the extent of the material around either AFGL490 or Elias 29. The results of the speckle interferometry and particularly red spectral slope imply that the infrared emitting region of SU Aur is confined to a disk, and that the disk is observed nearly edge-on.

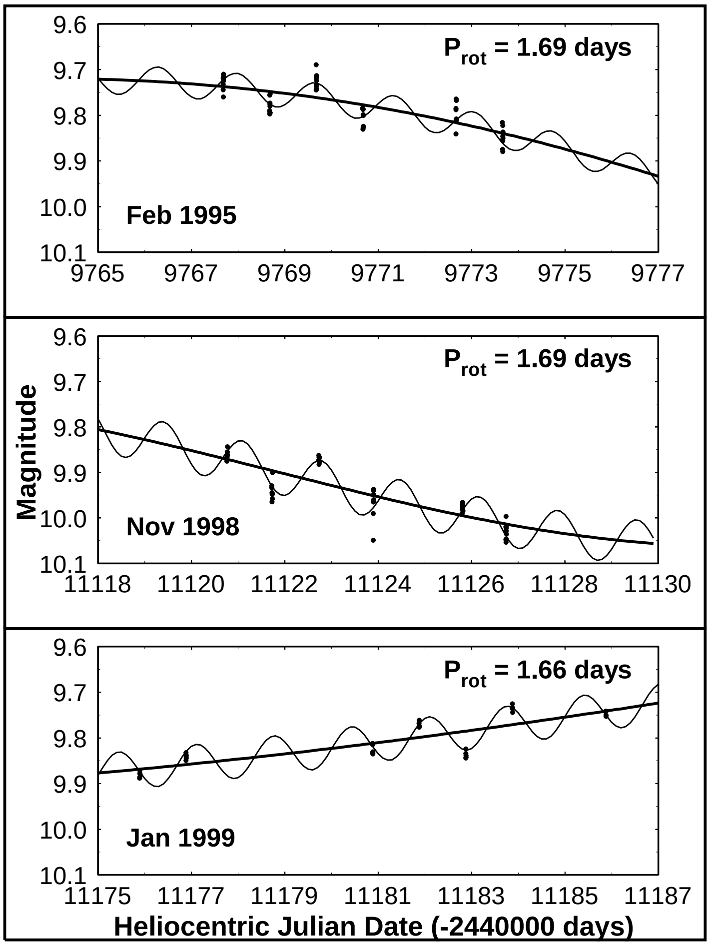


**Figure 2.** Three relatively constant sections of the SU Aurigae light curve. The rotational modulation of light due to starspots can be modelled by applying a direct (grid search) parameter optimization procedure. In all three cases a period of about 1.7 days was determined.

To find the rotation period of SU Aur from photometric data, appropriate sections of the light curve needed to be isolated. The rotation period is determined from the short-term, low amplitude, sinusoidal-like modulations in brightness due to the rotational effects of starspots. Many studies have established the rotation periods of T Tauri stars in this manner (see, for example, Bertout, 2000; Strassmeier *et al.*, 1999). Suitable portions of the light curve would each need to be $\sim 10$ days long — long enough to contain sufficient observations, but short enough to minimize the effects of possible spot creation, destruction, or migration. The sections selected also need to be relatively constant to avoid any rapid or significant drop in flux levels due to obscuration. Examination of our observations revealed three such regions, shown in Fig. 2. Using a straightforward sinusoidal model, we applied a direct parameter optimization procedure to find the period of rotation. This method is analogous to an iterative grid search in which each of the independent parameters are varied separately until the minimum in the sum of the deviations is achieved. A period of approximately 1.7 days was found for each of these sections. For the $b$ observations, we find the full range of the light modulations to be $0\overset{m}{.}064$, $0\overset{m}{.}098$, and $0\overset{m}{.}084$ for the 1995, 1998, and 1999 sections shown in Fig. 2. Hartmann *et al.* (1986) report a projected rotational velocity ($v \sin i$) of $66.2 \pm 4.6$ km/sec. From this high rotational velocity and the speckle interferometry results, we can assume that the inclination ($i$) is close to 90°. Therefore, the radius of the star can be determined,

$$R_{\rm rot} \sin i = P_{\rm rot} v(\sin i)/2\pi \simeq 2.2\ R_{\odot}.$$

Given that $L = 5.1\ L_{\odot}$ and $T_{\rm eff} = 5550$ K (Paper I), the above value can be compared to the photometrically determined radius,

$$R_{\rm phot} = \sqrt{L/(4\pi\sigma T_{\rm eff}^4)} \simeq 2.5\ R_{\odot}.$$

Since the visible light emissions come from the star and reprocessed light from the extended circumstellar material, the photometrically determined overall luminosity should be larger than the actual stellar luminosity. Also, the enshrouding dust would redden, and therefore possibly lower, the photometrically determined effective temperature. Hence, the photometrically determined radius should be expected to be larger than the actual radius of the star.

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